Space Technology Research Grants

Polymer Derived Ceramic Nanocomposites for Advanced Thermoelectrics

Completed Technology Project (2016 - 2020)

Project Introduction

In order to continue exploring deep space and to create the capabilities of allowing manned exploration to Mars and beyond, NASA has stated that it is vital to develop new power generation technologies that can power our future spacecraft more efficiently while simultaneously minimizing mass and maintaining reliability. Thermoelectric devices provide a simple way to convert heat into electricity without any moving parts promoting long-term, maintenance free operation. However, current state-of-the-art technologies are limited in that they achieve an operational efficiency of around 6-7%, are made of expensive and hazardous materials, and require a very large thermal gradient in order to produce any useable power. Over the last decade, theoretical and experimental work has proved that nanostructuring of the thermoelectric materials provides a very promising means for effectively increasing the operational efficiency through means of quantum confinement. Through quantum confinement, it has been shown that the electrical and thermal transport of a material can be decoupled and provide a means of increasing the efficiency through increasing the figure-of-merit, given by ZT=Î±2ÏƒT/Îº, where Î± is Seebeck coefficient, Ïƒ is electrical conductivity, and Îº is thermal conductivity. While various types of materials have been used to fabricate thermoelectrics with a decent ZT, thermally and chemically stable thermoelectric materials made from earth abundant materials are still required for deep space exploration. The research proposed within aims to further explore this area of nanostructured thermoelectrics by creating a new thermoelectric material based off of polymer-derived ceramics. Polymer-derived ceramics (PDCs) are a class of silicon-based, amorphous ceramic materials that are created through the thermal decomposition of polymeric precursors. PDCs offer a very high thermal stability (~1300-1500oC), have a high mechanical strength, as well as oxidation, corrosion, and irradiation stability. Like their polymeric precursors, they also possess an inherently low thermal conductivity. However, simple PDCs face the challenges of low electrical conductivity and charge carrier densities. It is hypothesized that 1) introducing anisotropic graphene fillers into the amorphous SiCN PDC matrix improves the charge transport efficiency but does not contribute significantly to phonon transport due to multiple length scale scattering; 2) the band structure of SiCN can be tuned for efficient charge transfer at SiCN/carbon interfaces; and 3) incorporating nickel nanoparticles into SiCN composite increases the scattering of low-energy electrons and reduces the electron-phonon coupling, leading to an increase of the figure-of-merit. To validate these hypotheses, I will first synthesize and characterize pure polymer-derived SiCN ceramics and the graphene/nanoparticle embedded SiCN nanocomposites followed by a synergistic structural characterization to understand how the ceramic composition and pyrolysis temperature affect the ceramic structures. The subsequent evaluation and comparison of the thermoelectric properties of pure SiCN and SiCN nanocomposites will reveal the effect of graphene, metal nanoparticles, and nanoscale structures on the charge carrier density, electrical conductivity, thermal conductivity, Seebeck coefficient, and the

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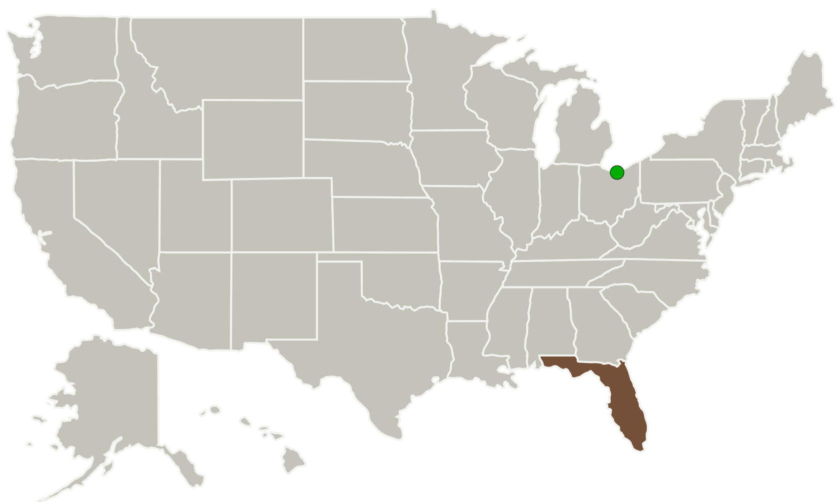
figure-of-merit ZT. Such understandings will provide scientific guidelines for the design, synthesis, and applications of PDC composites with significantly improved thermoelectric performance.

Anticipated Benefits

In order to continue exploring deep space and to create the capabilities of allowing manned exploration to Mars and beyond, NASA has stated that it is vital to develop new power generation technologies that can power our future spacecraft more efficiently while simultaneously minimizing mass and maintaining reliability. Such understandings will provide scientific guidelines for the design, synthesis, and applications of PDC composites with significantly improved thermoelectric performance.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
University of Central Florida(UCF)	Lead Organization	Academia Hispanic Serving Institutions (HSI)	Orlando, Florida
Glenn Research Center(GRC)	Supporting Organization	NASA Center	Cleveland, Ohio

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

University of Central Florida (UCF)

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

Lei Zhai

Co-Investigator:

Elizabeth Barrios

Primary U.S. Work Locations

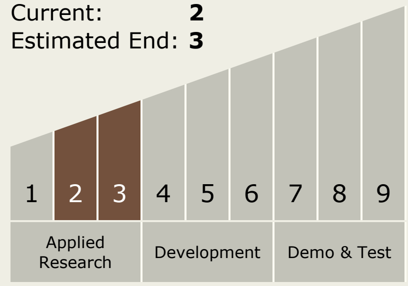
Florida

Project Website:

https://www.nasa.gov/strg#.VQb6T0jJzyE

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  └─ TX12.1 Materials
    └─ TX12.1.6 Materials for Electrical Power Generation, Energy Storage, Power Distribution and Electrical Machines

Target Destinations

Mars, Others Inside the Solar System